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Beck, Mathias ; Dieng, Mattias

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Cooperation Diversity and Innovation Performance: the Role of Firms' Research- and Development-Orientation

Mathias Beck*

University of Zurich, Department of Business Administration,
Affolternstrasse 56, CH-8050 Zurich, Switzerland.
E-mail: mathias.beck@business.uzh.ch

Mattias Dieng

University of Zurich, Department of Business Administration.
E-mail: mattias.dieng@gmail.com
* Corresponding author

Abstract: This study examines how diversity in R&D collaboration partners affects the innovation performance, as measured by each firm's sales share of innovative products taking into account the research versus development orientation of firms. To address this question, a large-scale sample of firm-level data from six waves (1999, 2002, 2005, 2008, 2011 and 2013) of the Swiss innovation survey is examined using a heteroscedastic-robust Tobit regression method. Results suggest that diversity positively affects the innovation performance of both firm types, but that the effects are strongest for research-oriented firms. In line with theoretical reasoning, a clear inverted U-shaped relationship between partner diversity and innovation performance is detected only for development-oriented firms and differences in effects are most pronounced for new-to-the-market innovations. In light of our findings, the study stresses the importance of partner *diversity* for research-oriented firms and (vertical) partner *selectivity* for development-oriented firms.

Keywords: R&D collaboration; R&D diversity; R&D partners; research orientation; development orientation; cooperation strategies; innovation performance; market novelties.

1 Introduction

The growing interest in openness in innovation – including industry-science collaboration – deserves more attention regarding the role of inter- and intra-organizational structures of knowledge creation and exchange. In-depth knowledge concerning both the opportunities and pitfalls of openness in organizations is highly needed. Indeed, the current literature calls for more research to better understand optimal organizational structures that explains how to effectively integrate knowledge from external sources into organizations (Cassiman and Veugelers, 2006; Dahlander and Gann, 2010; Laursen and Salter, 2014; Leiponen and Helfat, 2010; Sampson, 2007; Wallin and Von Krogh, 2010). This study examines how diversity in R&D collaboration affects innovation performance of research- versus development-oriented firms. Specifically, we derive more understanding for answers to questions such as, 'what are optimal levels of diversity of collaboration partners accounting for the research versus development orientation of firms?'

Empirical research indicates that a firm's innovation performance benefits from a higher collaboration intensity (Hottenrott and Lopes-Bento, 2014a) and from more diversity in its collaboration network (Beck and Schenker–Wicki, 2014), but also suggests that the marginal returns of collaboration are decreasing ("curvilinear effect"). These findings underline the importance of striking an appropriate balance between excessively broad and narrow search in the context of collaboration (Laursen and Salter, 2006). While recent studies have repeatedly confirmed the inverted U-shaped relationship between the diversity of collaboration partnerships and innovation performance, there is a gap of understanding of how this balance is affected when important firm characteristics and activities are taken into account. This study intends to fill this gap, and particularly considers an important dimension, which has so far not been addressed in this context: the firms' orientation towards *research* versus *development* activities.

While 'R' and 'D' have been mainly treated together in empirical work (Czarnitzki et al., 2011), it has long been pointed out that they relate to different environments (Mansfield, 1981) and firm structures (Link, 1982) and also constitute distinct activities per se (Barge-Gil and López, 2014). In this context, the risks and uncertainties commonly associated with R&D tend to be more pronounced in 'R' than in 'D' (Czarnitzki et al., 2011). Although these claims appear to have gone largely uncontested, the number of studies systematically distinguishing between 'R' and 'D' has remained low. Recently, however, there has been a slight resurgence of interest in this research-development dichotomy (Barge-Gil and López, 2015). A number of studies has recently analyzed the roles of public support and financial constraints as determinants of 'R' and 'D' activity (Clausen, 2009; Hottenrott et al., 2014); as well as the differentiated effects of 'R' and 'D' on innovation (Czarnitzki et al., 2009; Czarnitzki and Thorwarth, 2012; Karlsson et al., 2004). Surprisingly, however, such a distinction between 'R' and 'D' has not been systematically applied to the important context of collaboration diversity. This project aims to make a first step in this direction, by examining how R&D collaboration with diverse partners impacts innovation performance of research- OR development-oriented firms.

Specifically, following theoretical reasoning, this study investigates if the effect of partner diversity is stronger for research than for development-oriented firms. Additionally, as we assume that the relative marginal benefits of additional partners are smaller for development-oriented firms, we anticipate the inverted U-shape relationship between partner diversity and innovation performance is more pronounced for development-oriented firms. Moreover, in line with the economic rationale that diversity provides firms with more technological opportunities, the effects of diversified collaboration should be more pronounced for radical innovation outcomes. Finally, we are interested in how the geographical diversity of partners as well as partner type composition affect innovation outcomes of research- versus development-oriented firms. As an additional robustness test, we estimate if the effects are affected by the degree of innovation novelty.

To address our research questions, the study uses a methodology similar to previous studies in this field (Beck and Schenker–Wicki, 2014; de Leeuw et al., 2014; Faems et al., 2005). Like these studies, the analysis is based on innovation survey data, employs a Tobit regression method to estimate the effects of partner diversity on innovation performance and uses a set of widely accepted controls, and robustness checks. The group-specific effects of partner diversity are identified and compared by means of separate subsamples of research- and development-oriented firms, which closely follow typical features of research and development taken from theory.

In a nutshell, our results point to the importance of partner diversity for research-oriented firms and (vertical) partner selectivity for development-oriented firms. These results suggest that diversity positively affects innovation performance of both firm types, but that the effects are stronger for research-oriented firms. In line with theoretical predictions, a clear inverted U-shaped relationship between partner diversity and innovation performance is detected only for development-oriented firms and differences are more pronounced for more radical innovations which are new to the market. Interestingly, for research-oriented firms (given their frequent use of 'Science only' collaboration), there is ample evidence that for these firms, relying on a single science partner is usually not enough. Development-oriented firms, on the other hand, seem to benefit from selectivity in terms of their most used partner, namely by collaboration with vertical partners, notably, even when they are used in isolation.

Our research project contributes to the understanding of how firms in R&D alliances can enhance their innovativeness through a careful selection of their collaboration partners. This project clearly highlights the importance of alliance *portfolio diversity* for research-oriented firms and of *portfolio selectivity* for development-oriented firms. Strongly development-oriented firms need to be especially aware of the downsides of an excessively broad collaboration strategy, whereas strongly research-oriented firms may want to make more extensive use of such diversity.

2 Theoretical background

Joints effects of partnership

In the context of this paper, the resource-based perspective is particularly important to explain the distinct benefits which diverse collaboration can offer for research- and development-oriented firms in overcoming specific innovation obstacles. Furthermore, to give appropriate weight to the cost dimension of diverse collaboration, this perspective is complemented with transaction cost reasoning (Das and Teng, 2000; Penrose, 1959).[1] According to resource-based view, a firm needs to develop and strengthen its own resource base in order to achieve and maintain a sustainable competitive advantage.

To that end, collaboration can allow a firm to aggregate, share or exchange valuable resources with other organizations, especially resources, which it cannot efficiently create on its own or obtain through exchanges, mergers or acquisitions (Das and Teng, 2000). In particular, this can help firms pooling resources and exploiting resource complementarities, for example by jointly developing new products, the costs of which are beyond the capacity of an individual company. Hence, firms look to compensate for

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[1] As Tsang (2000) notes, the transaction cost and resource-based explanations are in part complementary. Resource-based theory and transaction cost economics are two essential 'lenses' used for the examination of joint ventures, and they are also specifically applied to studies of R&D cooperation (e.g. De Leeuw et al., 2014; Hottenrott & Lopes-Bento, 2014).

what they lack internally by searching for partners with resource configurations which best complement their own (Das and Teng, 2000). Particularly for successful innovation, the variety of resources required by a firm tends to be quite large (Teece, 1986). This can give cooperation a natural place in firms' development and exploitation of resources (Bogers and West, 2012).

As the outlined perspectives already suggest, firms' innovativeness can be enhanced, and sometimes even dependent upon, cooperation with external partners (Freeman, 1991). These may include universities and other research organizations (Jaffe, 1989), suppliers and users (Shaw, 1994), and even other firms (Coombs, 1996). Between these partners, there exists a vast heterogeneity in motives and purposes: in fact, each partner type can perform different functions and present distinct challenges (Sakakibara, 1997). Given this heterogeneity, it seems important to disaggregate R&D cooperation by partner type. The literature distinguishes between three broad categories of partners: (a) Partnerships with science, consisting of universities and other research institutions; (b) Vertical partnerships, consisting of customers and suppliers as well as (c) Horizontal partnerships, consisting of firms of the same industry. According to Belderbos, Carree, Diederen, et al. (2004) and Bolli and Woerter (2013) distinct motives and challenges are commonly associated with each partner.

This previous understanding of R&D collaboration has treated different partnerships as separate entities, largely independent from each other. However, given the increased speed and complexity of the technological environment, a single partner is rarely going to offer all solutions (de Leeuw et al., 2014). A considerable part of today's firms, therefore, maintains multiple partnerships at the same time (Belderbos et al., 2006). These aggregated effects between these partnerships can be more then the mere sum of their partial effects: as the previously outlined heterogeneity of functions suggests, different partner types may serve different purposes, potentially on different stages of the innovation process (Czarnitzki and Hottenrott, 2012). Following this rationale, it is easily conceivable that the effects of working with partners can be interdependent. For instance, searching for new research findings together with universities may only translate into successful product innovation if the focal firm is also able to effectively select, combine and transform these ideas into relevant products for the consumer.[1] For the latter purpose, collaboration with customers may be more effective and thus increase the standalone value of collaboration with universities. Conversely, working with universities may increase the standalone value of cooperating vertically, by providing fresh ideas and preventing the focal firm from being stuck in an existing trajectory. This would give rise to complementarities in the sense of (Milgrom and Roberts, 1995): cooperating with customers increases the marginal returns of cooperating with universities and vice-versa. Hence, rather than looking at the effects of a single partner, it becomes vital to also assess their effects jointly.

Empirical evidence supports the idea that important complementarities effects exist between different partners. In particular, Belderbos et al. (2006) find evidence that cooperation with customers increases firms' productivity growth both in combination with competitors and in combination with competitors and universities. Indeed, complementarities appear to exist between customer and competitor cooperation as well

[1] In the words of Doz et al. (2001), an organization which focuses only on 'sensing' is "knowledgeable but impotent" (p. 8): It has a plethora of good ideas but no effective structures to put them into practice.

as between customer and university cooperation. This is in line with the aforementioned idea that firms benefit from combining more basic forms of cooperation with forms of cooperation closer to the market: particularly customers may be instrumental in facilitating the acceptance and quick diffusion of innovations (Belderbos, Carree, Diederen, et al., 2004; Tether, 2002).[1]

However, combinations between partner categories also do not show the whole picture. The fact that some firms have resorted to network strategies involving complex interactions of *multiple* partnerships (de Leeuw et al., 2014) calls for an additional unit of analysis, the so-called 'alliance portfolio' (Faems et al., 2005; Wassmer, 2008).

Alliance portfolio diversity

Research concerned with such alliance portfolios, central to this paper, analyzes the focal firm and its alliances as an egocentric network. In this context, the alliance portfolio is defined as "the set of focal firm's active formal alliances" (de Leeuw et al., 2014, p. 1840). Hence, 'alliance portfolio *diversity*' (APD) is defined as the number of idiosyncratic alliance forms. In assessing this idiosyncrasy, it has become common to account not only for the aforementioned partner categories, but to also consider other relevant dimensions, whose characteristics differ in non-trivial ways (de Leeuw et al., 2014). This study follows Duysters and Lokshin (2011) and de Leeuw et al. (2014) in accounting for both partner types and their geographical distribution, distinguishing between domestic and cross-border partnerships.

There are good reasons to draw on geography as an additional dimension: requirements for R&D cooperation with a partner abroad may include dealing with a different culture and language (Joshi and Lahiri, 2014), but also adjustments to new regulations and laws. Many of the related issues may have to be dealt with on a continuous basis and can apply even if the firm already cooperates with the same partner type domestically. At the same time, these cross-border partnerships can bring radically new knowledge and other resources compared to what domestic partners offer (Meyer-Krahmer and Reger, 1999). Particularly firms requiring resources to innovate in new technological areas thus tend to cooperate intercontinentally (Miotti and Sachwald, 2003). Hence, in the sense of Cook and Brown (1999), each 'partner type / geography combination' is here treated as a separate search and learning space, embedded in its own distinct environment with non-local individuals, involving potentially different routines, habits and norms.

In general, drawing from such a diverse set of cooperation partners can be expected to affect firms' innovativeness (Beck and Schenker–Wicki, 2014). Specifically, evolutionary economics (Nelson and Winter, 1982) points to the importance of a wide range of external sources in increasing the variety of knowledge in a firm. Such variety fosters the firm's ability to create new combinations of technology and other knowledge (Laursen, 2012), and can thus increase its ability to innovate (Laursen and Salter, 2006). In that sense, diverse collaboration generally allows firms to access various

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[1] By contrast, combining suppliers with universities or competitors seems to exhibit a sub-additive effect on labour productivity (Belderbos et al., 2006). According to the authors, this could be due to supplier cooperation being less compatible with the more radical nature of these cooperation agreements, or with spillovers of valuable scientific knowledge to suppliers or competitors.

complementary resources (including knowledge, cf. Hottenrott and Lopes-Bento (2014b), which help them overcome internal limitations and resulting uncertainties in their innovation processes.[1]

However, as shown before, the logic of transaction cost economics also foreshadows some of the downsides of drawing from an excessive number of sources (cf. Laursen & Salter, 2006). More recently, research has started to place more emphasis on these limitations of broad innovation search processes (Laursen, 2012). The exploration of *non-linear effects* has thus become a focal point of research in the field, also in the area of alliance portfolio diversity.

The big picture: inverted U-shaped patterns

Here, an interesting picture has emerged in repeated observations: APD appears to increase innovative output only up to a certain ('tipping') point, where the costs start to outweigh the benefits. In particular, Duysters and Lokshin (2011), Oerlemans et al. (2013), Beck and Schenker–Wicki (2014), de Leeuw et al. (2014) and Zouaghi et al. (2015) have reported such a curvilinear or 'inverted U-shaped' relationship between partner diversity and innovation performance. Such a pattern is also backed by other findings related to search breadth, such as Katila and Ahuja (2002) and Laursen and Salter (2006) on knowledge sources; von Raesfeld et al. (2012) on the technological diversity between project partners as well as Hottenrott and Lopes-Bento (2014b) on firms' collaboration intensities.[2] Overall, the prevailing evidence indicates significant negative effects of 'over-searching'.

The choice of additional cooperation partners is, therefore, a decision that requires a careful consideration of the associated costs (Beck & Schenker-Wicki, 2014). Given the partners' embeddedness in distinct environments, each partner may require different organizational practices to manage (Laursen & Salter, 2006). With every new partner, the focal firm has to deal with new recurring issues such as coming to agreements, adapting the own organization, contracting and monitoring (Beers and Zand (2014), as well as the regulation of the appropriation of joint R&D results (Beck & Schenker-Wicki, 2014). Here, classic transaction cost drivers such as uncertainty and opportunism can come into play, giving rise to substantial costs related to the management, coordination and control of diverse partnerships (Knudsen and Mortensen, 2011).

These transaction costs must be borne for all partners simultaneously and can quickly overburden the capacities of a firm. Certain risks, particularly the risk of opportunism and of involuntarily spillovers (Combs and Ketchen, 1999) are also expected to rise with the number of partners.[3] Moreover, every investment in a partnership carries with it a degree

[1] The supposed positive effects of diverse cooperation have largely been supported empirically (e.g. Faems et al. (2005); Sampson (2007). Maintaining cooperative relations with diverse partners has been found to increase both the general likelihood of achieving product innovations (Becker & Dietz, 2004) as well as the specific likelihood of introducing more novel innovations (Nieto and Santamaria, 2007; Phelps, 2010).

[2] In the study by Hottenrott & Lopes-Bento (2014), collaboration intensity refers to the share of collaborative R&D projects in a firm's total number of R&D projects.

[3] Laursen & Salter (2014) find evidence that the inverted U-shaped effects of appropriability on diverse formal partnerships (which are the object of this study) are

of dependency on the partner (Teece, 1986). If these dependencies become too manifold, such 'over-embeddedness' can jeopardize firm performance (Uzzi, 1997), especially in the case of unforeseen events (Lokshin et al., 2011).

Given these rising costs and risks, managing diverse partnerships can constitute a highly unproductive drain of resources, unless each additional partner contributes substantial marginal benefits. These benefits may also be limited: every additional partner can only contribute so much useful information (Hottenrott and Lopes-Bento, 2014b), and firms with many partners may become subject to the 'attention allocation problem'. Because decision-makers must focus their scarce attention on a limited number of issues (Koput, 1997), only a limited number of ideas (e.g. from diverse partnerships) can be given the level of serious attention required for implementation.[1]

Hence, as Laursen and Salter (2006) and Phelps (2010) seem to suggest, innovativeness may be just as much dependent on an appropriate intensity of (repeatedly) engaging with a partner as it is on the number of diverse partner types.

While the general limitations of diverse partnerships have thus become quite evident, it seems less clear whether they apply to most firms in a similar fashion.

The role of research- and development-orientation

An important limitation in much of the previous innovation literature is the treatment of R&D as an inseparable process (Czarnitzki et al., 2011; Karlsson et al., 2004). Although it may sometimes be convenient or even necessary to treat R&D as a homogenous entity, researchers have long argued that the relative importance of its subcomponents may be as important as their total amount (Barge-Gil and López, 2015; Mansfield, 1981).

In essence, the umbrella term 'R&D' comprises three main components: basic research, applied research and development. Following the definitions given in the OECD Frascati Manual (2002), basic and applied research aim primarily at *acquiring new knowledge*, where only applied research has a particular application objective in view. By contrast, development *draws from existing research results and/or practical experience*, in order to create and implement new and improved products and processes. Hence, the most important and most salient differences are expected to be found between the two main components of research and development.

In their pursuit of product innovations, R&D active firms place differing emphasis on these two components (as reflected by the heterogeneity in relative R- and D-expenditures). While some firms base their product innovations largely on development (i.e. using little or no internal research), other firms take a more basic approach and aim at creating novel products with a substantial internal research component.

There is reason to suppose that these basic orientations matter for the way in which firms benefit from diverse collaboration. At the core of this idea are essential limitations, which limit inventive activity according to classic market failure theory and give rise to

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stronger than the effects of appropriability on 'softer', more general forms of openness pertaining to the use of separate knowledge sources.

[1] Other sources of inefficient resource allocation may add to this, such as the pursuit of ambiguous goals between different partnerships. According to Belderbos et al. (2006), pursuing multiple partnerships may be particularly problematic when these involve multiple objectives.

uncertainty in firms' innovation processes (Arrow, 1962; Nelson, 1959). Although these limiting factors can be ascribed to R&D as a whole (Martin and Scott, 2000), previous research has stressed that they are likely to be more applicable to 'R' than to 'D' (Czarnitzki and Hottenrott, 2012; Czarnitzki et al., 2011). Specifically, factors such as high project complexity and costs (Pisano, 1991), outcome uncertainty, intangibility, a lack of appropriability as well as related financing constraints are all expected to be more pronounced in the 'R' dimension of R&D.

In sum, this suggests that the hurdles to be overcome for successful product innovation tend to be particularly high for product innovations with a substantial research component. This is also reflected by the particularly high and diverse innovation obstacles faced by research-oriented firms in the Swiss innovation survey, giving rise to particularly high uncertainties in their innovation processes. In such an environment, cooperation can be a particularly effective way of supporting innovative activities: as previously outlined from a resource-based perspective, collaboration can help firms overcome crucial innovation obstacles, by providing access to complementary resources which are beyond individual firms' internal capacities (Park et al., 2002).[1]

This is not the end of the story, however: where the crucial obstacles are particularly diverse – as tends to be the case in research – the benefits of combining different partners become important. In these contexts, a single partner is hardly sufficient to help a firm overcome all crucial obstacles (which is necessary for successful product innovation to result). However, different partner types can (each) make a valuable contribution to this end.

A closer look at specific innovation obstacles may help illustrate this. Based on theory and data on innovation obstacles,[2] a variety of research-specific obstacles can be identified which give rise to differing diversity benefits in the above sense. Among these are (a) a lack of information on the state of technology, (b) financing and regulatory constraints as well as (c) difficulties in transforming research knowledge into marketable products. Previous studies suggest that to overcome each of these three research-specific obstacles, different cooperation partners may be instrumental.

(a) First, to mitigate the consequences of a lack of technological information, which should be particularly important in research (given its aim at acquiring new knowledge), science partners provide an affordable window to new technologies and allow firms to keep abreast of the latest developments (Tapon and Thong, 1999).
(b) Second, to mitigate financing constraints which have been found to be an important barrier to firms' research activities (Czarnitzki et al., 2011), horizontal partners are found to be particularly valuable (Czarnitzki and Hottenrott, 2012),: for instance, by helping firms spread their high research costs in a consortium (Hagedoorn and Schakenraad, 1990), a larger number of projects can be pursued, thereby potentially increasing the probability of successes of R&D efforts (Kotabe and Scott Swan, 1995). Horizontal cooperation may also help research-oriented firms to disseminate some of the project-specific risk (Tapon and Thong,

[1] Park et al. (2002), who study strategic alliances of semiconductor start-ups, find evidence that these firms (a) use strategic alliances to adapt to market uncertainties and (b) that 'resource-poor' firms are more likely to form such alliances.
[2] Results on the relative importance of innovation obstacles can be obtained from the authors.

1999) and signal the value of their intangible resources to investors (Czarnitzki and Hottenrott, 2012). As shown in the theory on the motives for horizontal cooperation, it can also be an effective way of dealing with regulatory problems (Nakamura, 2003). These tend to be especially high for research-oriented firms (see Figure 1), possibly due to the novel and sometimes-unknown nature of their products.

(c) Third, research-oriented firms may find it particularly difficult to transform research knowledge into marketable and accepted products. For these purposes, vertical cooperation may be instrumental, as indicated by the previous theory.

Hence, for successful innovation, research-oriented firms often tend to have a variety of specific obstacles to overcome. While each partner can make a valuable contribution to this end, often no single partner type is individually sufficient in helping a research-oriented firm do so. Therefore, if research-oriented firms make use of cooperation for innovation, a combination of different partner types appears as the most beneficial strategy: by using them together and thus making use of their diversity, the odds of passing all research-specific hurdles can be significantly increased.

For development-oriented firms, on the other hand, vertical cooperation seems instrumental. Given their closeness to the market and the relative continuity of their activities (Hottenrott et al., 2014; Karlsson et al., 2004), these firms are expected to profit extensively from continuous and sustained feedback loops along the value chain.[1] A combination of vertical cooperation with other partner categories, however, is not expected to offer the same complementarities as it does for research-oriented firms. Based on theory, science and (even more so) horizontal partners appear to offer specific benefits to research-oriented firms that are largely absent for many development-oriented firms. Therefore, while potentially helpful to foster innovations, it does not seem *vital* (at least in the medium term) for these firms to complement vertical collaboration with these more basic cooperation forms.

The supposed differences in diversity effects may be further compounded by effects of geographical diversity, especially in light of the fact that research-oriented firms seem to frequently target new geographical markets with their inventions.[2] This is important, because some of the research-specific obstacles must be overcome both domestically and abroad. For instance, regulations for new products differ across countries, as does consumers' acceptance of acceptance of new products. This points to additional benefits from geographically diverse partnerships for research-oriented firms. Previous studies indicate that particularly collaborating internationally can be an effective way for firms to facilitate expansion into these markets, to access local technological expertise and to reduce risks associated with new product introduction (Duysters and Lokshin, 2011).

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[1] For instance, Leifer and Triscari (1987) suggest that especially development units should ideally maintain close links with actual or potential customers.

[2] While development-oriented firms rank the goal of 'maintaining or increasing market share' (in current markets) as a much more important goal of their product innovation activities, research-oriented firms indicate the goal of 'accessing new regions as sales markets' as significantly more important. Even after controlling for other important factors, these innovation goals, as well as the overall severity of innovation obstacles, remain significantly associated with research- and development-orientation). Seemingly unrelated bivariate probit regression results on R- or D-orientation are available upon request from the authors.

Overall, the marginal benefits of diverse cooperation are thus expected to be higher for research-oriented firms than for development-oriented firms. Meanwhile, the marginal costs are deemed to be similar among the groups, following the logic of transaction cost economics. In light of these theoretical predictions, the main hypothesis is clear:

H1: The overall effect of partner diversity on innovation performance is stronger for research-oriented firms.

The limited marginal benefits of additional partners for development-oriented firms further imply that for these firms, the costs of diverse partnerships have more of a bearing: because for development-oriented firms, the supposed marginal costs are large *relative* to the (moderate) marginal benefits, they are expected to catch up with the marginal benefits much sooner.[1]

Hence, for these firms, the existence of a turning point can be expected over the observed range of partners, where the marginal benefits are more than offset by the marginal costs and beyond which the net benefits of cooperation decline rapidly.

H2: For development-oriented firms, the relationship between partner diversity and innovation performance follows an inverted U-shape.

Turning to the different subcomponents of innovation performance, more specific predictions can be made. As the previous part has established, particularly high (or diverse) obstacles must be overcome to bring about successful innovations with a strong internal research component. To better overcome these hurdles, cooperating with diverse partners can be an effective strategy. However, being faced with high hurdles may also end up having its advantages: once these high obstacles are overcome (i.e., the innovations are successfully realized and reach the marketplace), the inherent novelty potential of the resulting innovations tends to be greater. A firm that has pursued product innovation with basic research methods (and in the process, possibly ventured into previously unknown territories) may be rewarded with a finished product, which strongly differs from what has previously been known.

Following this rationale, the effects of diverse cooperation in helping research-oriented firms overcome their innovation obstacles should result particularly in innovations new to the market. In other words, the distinct effects on this outcome measure should be most pronounced.

H3: The differences in effects are strongest on market novelties.

While H1-H3 are assessed in terms of a 'compound measure' for alliance portfolio diversity (including both diversity in partner categories and geography), the previous arguments imply that even if these two types of diversity are disaggregated, diversity effects should still be observable. Therefore, an additional hypothesis concerns the separate effects of different partner combinations (vertical, horizontal and science) and geographical diversity (domestic and/or abroad).

H4: Both in terms of partner categories and partner geography, diversity has a stronger impact on the innovation performance of research-oriented firms.

[1] An exemplary representation and simulation of the supposed relationships can be obtained from the authors.

Empirical strategy

Data

The empirical analysis uses micro-aggregated firm-level data of Swiss firms, derived from six waves of the Swiss innovation survey (years 1999, 2002, 2005, 2008, 2011 and 2013). The Swiss innovation survey is a postal survey conducted by the KOF Swiss Economic Institute at ETH Zurich, based on a disproportionate stratified random sample of Swiss firms with at least five employees, covering all relevant manufacturing, service and construction sectors (Beck and Schenker–Wicki, 2014). In its setup, it is largely aligned to the European Community Innovation Survey ('CIS'), which is based on OECD guidelines (OECD, 1992). The survey is therefore subject-oriented, periodically asking firms to provide detailed information on their R&D and innovation activities as well as on structural characteristics and market conditions.[1] After eliminating non-innovating firms, missing observations and firms without indication of R&D expenditures, the main sample contains 1,903 firms and 3,757 observations.[2]

Outcome Measures

Because CIS data are widely used and many of the above-mentioned empirical studies are CIS-based, this data allow for the use of widely accepted measures.

The main dependent variable is each firm's *innovation performance*, as measured by the share of new or significantly improved product turnover in total firm turnover (*INNO_SALES*), ranging from 0 to 100. Following the Oslo Manual (OECD, 1992), products must be (at least) new to the firm or modified in a *substantial* way to conform to this definition.[3] This measure for innovation performance has been used in several key contributions (Belderbos, Carree and Lokshin, 2004; Grimpe and Kaiser, 2010) (Duysters and Lokshin, 2011) and has gained widespread acceptance in empirical analysis.

We follow influential studies in the field in employing a time lag for the outcome variable Belderbos et al. (2006) regarding the effects on productivity growth and similarly de Leeuw et al. (2014) for innovation performance). To allow for an appropriate time span during which the results of R&D collaboration can result in innovation performance, each firm's innovation performance recorded in the subsequent survey wave is used, where available. Exactly corresponding to the assumption made by Belderbos, Carree and Lokshin (2004) for the effects of cooperation on productivity growth, it is therefore supposed that R&D collaboration in years (t-2) to (t) should have

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[1] The response rates from the survey were 33.8% (1999), 39.6% (2002), 38.7% (2005), 36.1% (2008), 35.9% (2011) and 32.7% (2013).

[2] As this study looks at research- and development-oriented firms and the effects of R&D collaboration, observations of firms indicating no importance of R&D expenditures could not be examined in addition to missing observations (1190 observations). Although the resulting omission of R&D inactive firms causes increases in firms' average competitiveness (higher average values for variables such as R&D intensity and innovation performance), structural differences compared to the overall sample appear unsystematic. Still, the results should be interpreted for firms with R&D expenditures.

[3] This excludes products with only minor adjustments, such as mere design changes or customer specifications.

its main impact on product innovation in periods (t) to (t+2), where (t) denotes the year in which the survey was undertaken and (t+1) the following year.[1] Although no 3-year period can capture the entire impact of R&D collaboration, such a time frame appears both proximate and long enough to capture the most important effects. At the same time, using a time lag may reduce simultaneity-related problems, which are quite common in innovation survey data (Mairesse and Mohnen, 2010).

To provide further insights, additional regressions use subcomponents of innovative sales as their dependent variable, as depicted in Table 1 below.

Table 1 Subcomponents of innovative sales

<table>
<tr><td colspan="3">(Overall) innovative sales: new or significantly improved products</td></tr>
<tr><td colspan="2">New products</td><td rowspan="2">Sig. improved products</td></tr>
<tr><td>Market novelties</td><td>Firm novelties</td></tr>
</table>

Main effects (alliance portfolio diversity and partner combinations)

To examine how the diversity of partner types affects innovation performance (hypotheses 1-3), the *alliance portfolio diversity (APD*) is used as the main explanatory variable. As aforementioned, this variable is defined following Oerlemans et al. (2013) and de Leeuw et al. (2014), based on binary information on each firm's partner types and their geographic distribution (domestic or abroad). Cooperative agreements are distinguished by means of seven partner types: *customers, suppliers, competitors, non-competing firms, firms belonging to the same corporate group, universities and other research institutions*, each of whom constitutes a separate partner domestically and abroad. APD is then calculated by (a) dividing each firm's number of partners by the maximum possible number of partners (in this case 14) and (b) taking the squared term of this division. To examine potentially important non-linear effects (Laursen and Salter, 2006), a squared term of this APD variable (*APD_Sq*) is included (de Leeuw et al., 2014; Oerlemans et al., 2013).

As a consistency check (hypothesis 4) and to gain further insights into the underlying complementarities, additional regressions examine the performance effects of (mutually exclusive) *partner combinations*. As shown in Beck and Lopes-Bento (2015), this amounts to eight constellations (Table 2):

[1] For instance, according to the exact wording of the Swiws innovation survey, the 2008 survey (t) asks about collaboraiton activities from 2006 to 2008 (t-2 to t) and the subsequent 2011 survey asks about sales in 2010 *resulting from products introduced since the beginning of 2008* (t to t+2).

Table 2 Operationalization of simultaneous partner combinations

No.	(S V H)	Label
1	(0 0 0)	No partner category used
2	(0 0 1)	Horizontal only
3	(0 1 0)	Vertical only
4	(1 0 0)	Science only
5	(0 1 1)	Vert. & Hor.
6	(1 0 1)	Scie. & Hor.
7	(1 1 0)	Scie. & Vert.
8	(1 1 1)	All categories used

Source: Modified from Beck and Lopes-Bento (2015).

Controls

Our analysis applies a set of well-established controls to limit unobserved firm and industry heterogeneity. Firstly, virtually all related studies control for firm size. Although its influence on the propensity to cooperate is ambiguous, it may influence the relationships in a variety of ways, especially in light of recently detected moderating effects ((Beck and Schenker–Wicki, 2014). Here, firm size is measured by the number of employees (regressed in terms of 100 employees, to facilitate interpretation). Because this variable is highly skewed, its values enter in logarithms (*lnFIRMSIZE*). Furthermore, non-linear effects of firm size on the propensity to collaborate (Cassiman and Veugelers, 2002) are accounted for by using a squared term.

Though closely related to firm size (Barge-Gil and López, 2014), firms' age *(FIRM_AGE)* assumes a special role: young firms may be characterized by a particularly high degree of innovative activity (Czarnitzki and Hottenrott, 2012), especially to gain market access (Beck and Schenker–Wicki, 2014).

A firm's R&D activity is not only directly related to higher innovation performance, but it also tends to increase its ability to assimilate and exploit external information (Cohen and Levinthal, 1990). This renders it a potentially important factor for the degree to which firms can benefit from diverse partners. In line with other studies, each firm's R&D intensity *(RND_INT)* is used to control for this 'absorptive capacity'. However, internal R&D can only partly capture its effects (Sofka and Grimpe, 2010): authors have pointed to other important elements of a firm's absorptive capacity, particularly human resources (Muscio, 2007; Rothwell and Dodgson, 1991). To capture these 'softer' determinants of absorptive capacity, we include a measure for the education level of the workforce, the *share of employees with tertiary education (TERT_EDUC_SH)* (Beck and Schenker–Wicki, 2014). Other important factors, which tend to influence the relationships of interest, can be found in a firm's environment. For instance, firms competing in international markets tend to face more intense pressures to innovate

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(Kirner et al., 2009). Following Abramovsky et al. (2009), de Faria et al. (2010), and Beck et al. (2016), regressions therefore include the *share of firms' exports in total turnover (EXPORT_SH),* to proxy for the degree of competitiveness a firm is facing.

The technological knowledge available in a firm's environment, offering potential for innovations in its area of activity, may further influence both its propensity to cooperate and its innovative activity *(TECH_POT)*. Finally, unobserved industry-specific and time-varying effects are accounted for with 9 industry dummies and six year dummies for the respective survey waves.

Estimation

Taking into account that a significant share of the firms in the sample does not generate innovative sales in every given period, the outcome measures for innovation performance are characterized by a corner solution around zero (Tobin, 1958). To account for these censored dependent variables, Tobit models are used (left-censored at zero).[1] Innovation performance is thus modelled as follows:

$$\begin{aligned} \mathrm{INNO\_SALES}^*_{i,t+1} &= \alpha + \beta_1{*}\mathrm{APD}_{i,t} + \beta_2{*}\mathrm{APD\_Sq}_{i,t} + \beta_3{*}\mathrm{lnFIRMSIZE}_{i,t} \\ &+ \beta_4{*}\mathrm{lnFIRMSIZE\_Sq}_{i,t} + \beta_5{*}\mathrm{FIRMAGE}_i + \beta_6{*}\mathrm{RND\_INT}_{i,t} + \beta_7{*}\mathrm{TERT\_EDUC}_{i,t} \\ &+ \beta_8{*}\ \mathrm{EXPORT\_SH}_{i,t} + \beta_9{*}\mathrm{TECH\_POT}_{i,t} + \beta_{10\text{-}18}{*}\mathrm{SEC2\text{-}9}_i + \beta_{19\text{-}23}{*}\mathrm{YEA} \\ &\mathrm{YEAR13}_t + \varepsilon,\ \varepsilon \sim \text{i.i.d. } N(0, \sigma^2). \end{aligned} \tag{1}$$

whereas,

$$\mathrm{INNO\_SALES}_{i,\,t+1} = \begin{cases} \mathrm{INNO\_SALES}^*_{i,t+1}, \text{if } \left(\alpha + X'_{i,t}\beta + \varepsilon\right) > 0 \\ 0, \text{otherwise} \end{cases} \tag{2}$$

As stated by Wooldridge (2010), standard Tobit model estimation requires the assumption of homoscedasticity in order to be consistent. As likelihood ratio tests indicate the presence of severe heteroscedasticity in the regressions, heteroscedastic robust Tobit models are estimated by maximum likelihood, following Beck et al. (2016). In order to estimate heteroscedastic Tobit models consistently, the homoscedastic standard error term σ is to be replaced by $\sigma_i = \sigma\exp(Z'\alpha)$ in the likelihood function (Greene, 2003). Here, groupwise multiplicative heteroscedasticity is considered by including firm size and industry dummies.

Furthermore, as many firms appear repeatedly in the sample, standard errors are clustered at the firm level. To test for significant between-group differences in APD coefficients, a Hausman-type test as described is used (de Leeuw et al., 2014).

Besides, we perform additional regressions on the subcomponents of innovation performance in order to test the robustness of our results. Further robustness checks include a step-wise inclusion of additional controls; the exclusion of lagged dependent variables, and the omission of systematic outliers (R&D service firms) potentially causing between-group differences with potential influence on the results.

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[1] Previous studies further point to Tobit regression models as the predominant method used to examine the effects of alliance portfolio diversity on innovation performance (e.g. Faems et al., 2005; Oerlemans et al., 2013; De Leeuw et al., 2014; Beck & Schenker-Wicki, 2014).

Categorization of firms

As indicated previously, the essential between-group differences are assessed by means of subsamples of research- and development-oriented firms. To analyze firms' 'R' and 'D' as distinct activities, previous studies rely on firm-level expenditure data (e.g. Barge-Gil & López, 2014; Hottenrott et al., 2014). Data on R&D expenditures is also collected in the Swiss innovation survey. Here, firms are asked to indicate the magnitude of their expenditures in research and development for their product innovation activities in Switzerland on a five-point Likert scale (from 1= 'none' to 5 = 'very high'). It should be noted that this is a qualitative measure, unlike the quantitative measures used in other studies distinguishing between 'R' and 'D'. However, it has been found that the informative content of the two measurement types tends to be similar (Arvanitis (Arvanitis and Hollenstein, 2001). Moreover, historical evidence (Godin, 2006)) and current accounting regulations suggest that firms may often lack systematic accounting practices to assess their separate research and development expenditures with precision. In that regard, the more qualitative data collected by the Swiss innovation survey may even be more reliable, as it is potentially less prone to measurement errors than survey data asking for absolute expenditures.

Using this information, firms are categorized relying on the relative importance of R- and/or D- expenditures. For the creation of reliable subsamples, three essential preconditions had to be met: (a) The logic of the categorization should be in line with the basic idea outlined in the theoretical part, (b) the group characteristics should be consistent with theory and intuition and (c) the categorization should not be contaminated by systematic between-group differences which are unrelated to the relative importance of research and development and systematically influence other measures.

The following categorization has been found to best fulfill all three criteria: A firm was categorized as *research-oriented* if its average indicated score of research expenditures for product innovation (during its participation in the survey) is at least as high as its average indicated score of development expenditures for product innovation, and as *development-oriented* otherwise.[1]

(a) First, the result of this categorization closely adheres to the two basic approaches outlined in the theory part. On average, development-oriented firms indicate expenditure scores of (R/D)=(1.75/3.30), suggesting that their product innovations are largely based on development, whereas research-oriented firms indicate average scores of (3.01/2.90), suggesting that their product innovations contain a substantial internal research component.

(b) Second, the categorization turned out to be highly consistent with theory and intuitive expectations. Both regarding key characteristics and collaboration patterns, research-oriented firms rank higher on dimensions, which are commonly associated to research, while development-oriented firms rank higher on typical development-related dimensions.

(c) Third and perhaps most importantly, the categorization appears to be free from systematic between-group differences. In alternative categorizations based on

[1] More information on the detailed classification of firms into subsamples are available from the authors upon request.

relative R- and D-expenditures *between* firms, for instance, the firms with higher scores on the 'R' dimension would rank systematically higher on virtually every key indicator of innovativeness, including R&D cooperation. This is because firms with high scores on the research dimension usually also score high on the development dimension, but not necessarily vice-versa.[1] Thus, a categorization of firms based on *between*-firm comparisons or absolute cut-offs would lead to highly unbalanced relationships. Here, high-profile innovators would systematically more often be assigned to the research-oriented group, giving rise to severe endogeneity problems.

By directly comparing the R- and D- expenditures *within* firms, the categorization used in this study essentially gives each firm the same chance of being in either subsample, despite the existence of complementarities. In that way, this relative (within-firm) categorization avoids systematic differences between the groups, while at the same time maintaining a high degree of consistency.[2]

Results and discussion

Descriptive statistics

Table 3 shows summary statistics for the full sample of firms observed. Exactly as in De Leeuw et al. (2014) who examine the same 14 partners, the average APD for the full sample amounts to 0.04, corresponding to an average of 2.8 partner types. Overall, the magnitude of the variables is in line with expectations and the main variables are close to equal between the groups. However, regarding the controls, significant between-group differences in firm age, 'tertiary education' and R&D intensity seem noteworthy. While lower firm age, lower export shares and higher education levels in research-oriented firms are unsurprising based on previous research (e.g. Barge-Gil & López, 2014), the differences in R&D intensity merit closer attention.[3]

For more detailed information of the group-specific characteristics, seemingly unrelated bivariate probit regressions were calculated to examine the association of

[1] This is highly consistent with the findings of previous studies, suggesting that the two activities exhibit complementarities (see e.g. Hottenrott & Lopes-Bento, 2014, for a detailed discussion). In other words, high 'R' rarely comes without high 'D' in a firm, but high 'D' often comes without high 'R'.

[2] An important caveat of this categorization is that also firms with lower scores on both dimensions (e.g. 2/2) are categorized as either research- or development-oriented. However, this has not been found to cause any serious inconsistencies. In turn, it allows the following regressions to cover the entire spectrum of firms' R&D intensities, with subsamples that allow for useful comparisons.

[3] These differences stem from outliers: all service firms with R&D intensity above 50% belong to commercial service branches, strongly suggesting that these are service firms with R&D as their core business. Due to the nature of their activities, these firms are systematically assigned to the group of research-oriented firms, significantly increasing the R&D intensity of this group. However, the associated between-group differences are not found to influence the key results. Because the outliers are genuine (no measurement errors), they are nevertheless included in the other regressions. Additional tables showing these results can be provided by the authors upon request.

various factors with the likelihood of an innovating firm being research- and development-oriented.[1] Results are consistent with theory and expectations: most notably, the goal of 'accessing new regions as sales markets' and the 'overall severity of innovation obstacles' remain significantly associated with research-orientation, even when controlled against other important factors.

Regarding these obstacles, the previous hypotheses relied on rather specific statements, which require consistency with the data. Figure 1 below thus presents information on 21 innovation obstacles, for a large share of the selected sample. Firstly, it can be seen that the two research-specific obstacles 'lack of public support for technology diffusion' and 'lack of public support for research' show the largest differences between research- and development-oriented firms (t=-6.04 and t = -6.06). This is reassuring in the sense that firms appear to have been categorized correctly. Beyond that, between-group comparisons of obstacles indeed show significant differences in three key dimensions outlined previously: (a) technological information, (b) financing constraints (internal and external), and (c) regulation (including market access). These specific obstacles are expected to constitute major drivers of differing collaboration benefits.

More detailed information of industry distributions shows further interesting patterns.[2] Research-oriented firms are relatively frequent in chemicals industries (p = 0.0000, which includes pharmaceuticals) as well as wholesale and retail trade (p = 0.0000 and p = 0.0262, respectively). Development-oriented firms, on the other hand, appear to be most prevalent in 'engineering-intensive' industries, notably machinery & equipment (p=0.0000), electrical engineering (p = 0.0004) and electronics & instruments (p = 0.0001).

With regard to cooperation patterns, the expected tendencies can be discerned (see Table 5): vertical cooperation appears to be frequently used by development-oriented firms, while science cooperation tends to be more often utilized by research-oriented firms. Apart from that, there is a slight indication of differences in horizontal cooperation. However, these differences barely fail to reach conventional significance levels.

[1] Results are available by the authors.
[2] Results are available by the authors.

Table 3 Summary statistics and cross-correlation matrix

No.	Variable	Obs.	Mean	S.D.	Min.	Max.	y	1	2	3	4	5	6	7	8
y	Innovative sales	3,757	28.54	26.97	0	100	1.00								
1	APD	3,757	0.04	0.10	0	1	0.13	1.00							
2	Firm Size	3,757	258.56	1,237.12	1	39899	0.01	0.21	1.00						
3	Firm Size Squared	3,757	1,596,932	38,400,000	1	1.59E+09	0.00	0.12	0.90	1.00					
4	Firm Age	3,757	59.96	42.44	1	645	-0.14	0.03	0.06	-0.02	1.00				
5	R&D Intensity	3,757	2.92	7.27	0	178.79	0.25	0.13	0.01	0.00	-0.11	1.00			
6	Share Tert. Educated	3,757	7.37	12.65	0	100	0.13	0.12	0.04	0.00	-0.14	0.30	1.00		
7	Tech. Potential	3,757	50.92	27.42	0	100	0.19	0.19	0.07	0.03	-0.07	0.17	0.21	1.00	
8	Export share	3,757	37.29	37.66	0	100	0.21	0.23	0.03	-0.01	-0.05	0.22	0.13	0.24	1.00

Notes: Firm size is here represented in original units.

Table 4 Summary statistics by group and between-group differences

Variables (Total N = 3757)		R-oriented n = 637		D-oriented n = 3,120		Result of t-tests Tech. Potential on mean differences	
No.	Variable name	Mean	S.D.	Mean	S.D.	p-Value, incl. outliers	p-Value, excl. outliers
y	Innovative sales	27.10	26.88	28.84	26.98	0.1384	0.0563*
1	APD	0.04	0.12	0.04	0.10	0.2089	0.3187
2	Firm Size	296.10	1373.11	250.90	1207.58	0.4008	0.4008
3	Firm Size_Sq	1,970,135	$4.1*10^7$	1,520,736	$2.3*10^7$	0.7876	0.7792
4	Firm Age	55.86	45.97	60.79	41.64	0.0075***	0.0072***
5	R&D Intensity	3.72	10.59	2.76	6.38	0.0024***	0.6564
6	Share Tert. Educ.	8.60	15.27	7.12	12.03	0.0071***	0.0876*
7	Tech. Potential	50.71	29.10	50.96	27.06	0.8306	0.6419
8	Export share	33.63	38.58	38.04	37.44	0.0070***	0.0028***

Notes: The variable for technological potential has been rescaled to value range [0,100].

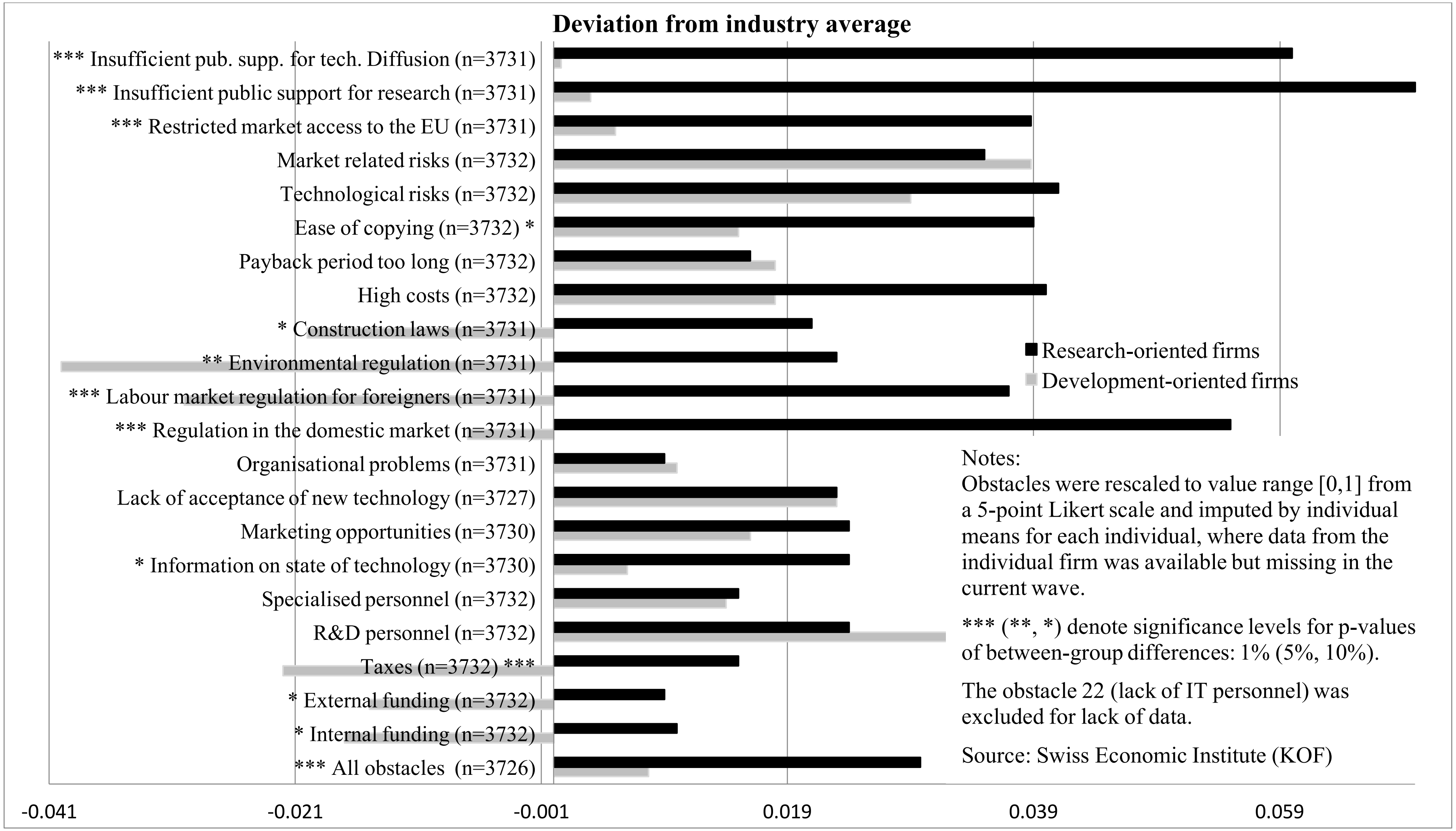


Figure 1 Relative impact of various obstacles on the innovation process

Table 5 Collaboration partner types by subsample

No.	Label	R-oriented firms (n=188 cooperating)	D-oriented firms (n=971 cooperating)	t-value of mean difference (D-R)
1	Customers Y/N	58.5%	**64.8%**	t = 1.6370 p = 0.1019
2	Suppliers Y/N	68.1%	68.8%	t = 0.1919 p = 0.8478
3	Same industry (Comp.) Y/N	**37.2%**	32.9%	t = -1.1641 p = 0.2446
4	Other industry (NComp.) Y/N	38.3%	38.7%	t = 0.1095 p = 0.9129
5	Group Y/N	38.3%	41.6%	t = 0.8436 p = 0.3991
6	Universities Y/N	**62.2%**	55.7%	t = -1.6518* p = 0.0988
7	Other Res. institutions (Y/N)	**34.6%**	27.3%	t = -2.0272** p = 0.0428
	Total	100%	100%	-

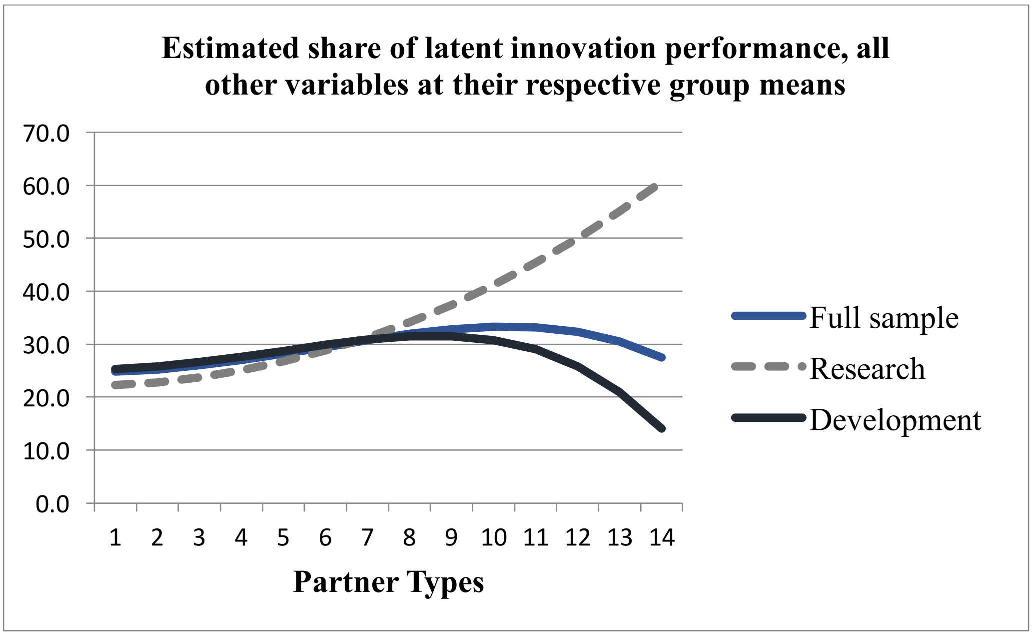
Note: 70.5% of research-oriented and 68.9% development-oriented firms cooperate with at least one partner (t = -8.008, p = 0.4233).

Impact of partner diversity on innovation performance

Table 6 presents the results of the heteroscedastic-robust Tobit regressions with overall innovative sales as the dependent variable. In the table, blocks (1) and (2) constitute different model specifications and the sub columns show the results for the respective samples (full sample = sample of research-oriented firms + sample of development-oriented firms). Overall, the results confirm the positive yet limited effects of partner diversity found in previous studies. Despite controls, the APD linear coefficient is significantly positive for the full sample (1). However, the simultaneously significant negative squared term indicates an inverted U-shaped pattern between APD and innovation performance, which exhibits a tipping point at about 10 partners (2).[1] Beyond that, interesting differences can be discerned for research- and development-oriented firms. As indicated by the APD linear coefficients, partner diversity positively affects the innovation performance in both firm types, but to a lesser extent in development-oriented

[1] The estimated tipping point (or *optimal APD*) can be calculated by dividing the negative APD linear coefficient by 2 times the APD squared coefficient. This follows from a simple quadratic formula of the form f(x) = ax2 + bx + c, where b corresponds to the APD linear coefficient and a to the APD squared coefficient, which solves to to $x_{Top} = -b/2a$ when derived by x. Then, to calculate estimated *optimal number of partner types*, one simply reverses the calculation of the APD formula (by taking the square root of the optimal APD and multiplying it by 14, De Leeuw et al., 2014).

firms (p=0.0299 for differences in the linear coefficient). Moreover, the existence of a clear inverted U-shape is detected only for development-oriented firms. Figure 2 presents the estimated patterns.



Note: keeping control variables at their respective group means and modifying only APD.

Figure 2 Estimated relationships: partner types and innovation performance

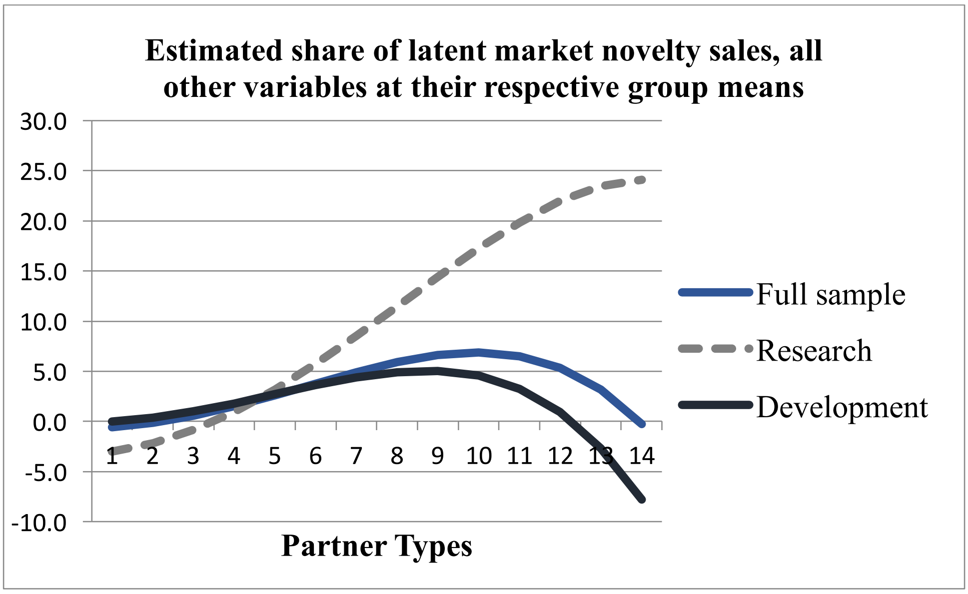


Figure 3 Estimated relationships: partner types and market novelty sales

Table 6 APD and innovation performance: Tobit regression estimates

Dependent variable: sales share of new and sig. improved products	(1) APD			(2) APD with squared term		
	Full	Research	Develop.	Full	Research	Develop.
H1. APD	16.68***	37.73***	11.49**	31.84***	36.43*	34.28***
	(4.504)	(9.209)	(5.094)	(9.416)	(19.99)	(10.44)
H2. APD Squared				-28.98*	2.076	-45.29**
				(15.80)	(28.33)	(18.09)
Tipping point (opt. no. of Partners)				*10.38*	-	*8.61*
Log Firm Size	-4.513***	-2.716	-5.449***	-4.689***	-2.707	-5.736***
	(1.582)	(3.423)	(1.805)	(1.584)	(3.426)	(1.807)
Log Firm Size Sq.	1.166***	-0.000	1.737***	1.226***	0.000	1.842***
	(0.448)	(0.817)	(0.533)	(0.449)	(0.817)	(0.535)
Firm Age	-0.033***	-0.047*	-0.035***	-0.034***	-0.047*	-0.035***
	(0.011)	(0.026)	(0.013)	(0.011)	(0.026)	(0.013)
R&D Intensity	0.620***	0.575***	0.672***	0.617***	0.575***	0.663***
	(0.072)	(0.136)	(0.087)	(0.072)	(0.136)	(0.087)
Share Tert. Educ.	0.102**	0.216**	0.101*	0.101**	0.217**	0.101*
	(0.049)	(0.104)	(0.055)	(0.049)	(0.105)	(0.055)
Tech. Potential	0.102***	0.002	0.119***	0.099***	0.002	0.116***
	(0.018)	(0.044)	(0.020)	(0.018)	(0.044)	(0.020)
Export Share	0.079***	0.050	0.082***	0.078***	0.050	0.081***
	(0.015)	(0.036)	(0.017)	(0.015)	(0.036)	(0.017)
9 Industry Dummies	$\chi 2$ (8) = 157.36***	$\chi 2$ (8) = 64.36***	$\chi 2$ (8) = 124.69***	$\chi 2$ (8) = 158.00***	$\chi 2$ (8) = 64.33***	$\chi 2$ (8) = 126.15***
6 Year Dummies	$\chi 2$ (5) = 42.24***	$\chi 2$ (5) = 6.30	$\chi 2$ (5) = 49.87***	$\chi 2$ (5) = 42.29***	$\chi 2$ (5) = 6.25	$\chi 2$ (5) = 50.13***
Constant	14.88***	22.12***	13.67***	14.75***	22.14***	13.47***
	(2.051)	(4.769)	(2.275)	(2.051)	(4.771)	(2.274)
Total observations	3,757	637	3,120	3,757	637	3,120
(uncensored)	(3,116)	(513)	(2,603)	(3,116)	(513)	(2,603)
Wald $\chi 2$	607.90***	165.66***	516.85***	611.39***	165.61***	523.61***
Prob > $\chi 2$	0.000	0.000	0.000	0.000	0.000	0.000
Log Likelihood	-15,449	-2,539	-12,871	-15,447	-2,539	-12,868

Notes: Standard errors in parentheses (clustered at the firm level).
*,(**,***) Denotes significance at the 10% (5%, 1%) test level.

Further analysis aims at examining the underlying relationships in more detail. Though not directly comparable, the results on subcomponents of innovative sales strongly indicate that the specific differences in effects are strongest with market novelties as the dependent variable.[1] Although the estimated APD coefficients are larger for research-oriented firms with regard to all subcomponents of innovative sales, they are found to differ significantly only with market novelty sales as the dependent variable (p=0.0298). The estimated relationships between partner diversity and market novelty sales are presented in Figure 3. Here, the research-specific effects of partner diversity appear most pronounced. While a clear and strong inverted U-shape is indicated for development-oriented firms, a near-linear relationship is estimated for research-oriented firms.[2]

As an extension to Beck & Schenker-Wicki (2014), the study furthermore examined whether the estimated effects of partner diversity differ significantly by firm size. This was done by interacting APD with the continuous firm size measure, to have both baseline effects and the interaction simultaneously in the model. Indeed, a negative interaction effect between firm size and APD was found for new product sales.[3] However, no conclusive differences regarding these interactions could be discerned between research-and development-oriented firms.

Impact of partner combinations on innovation performance

In order to explore the underlying mechanisms in more detail, further regressions disaggregate the APD measure, looking separately at (1) the effects of mutually exclusive partner combinations and (2) the use of partners domestically and/or abroad.

Table 7 presents these results, again with innovation performance (overall innovative sales) as the dependent variable. Here, the positive effects of diversity on the innovation performance of research-oriented firms become even more clear: the coefficient for a combination of all partner categories (Vert. & Hor. & Scie.) has by far the highest

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[1] Although the number of observations for firm and market novelties is smaller (fewer firms indicated these), no clear differences to the overall sample were detected, except for the loss of a survey wave, which has been accounted for in the regressions. Moreover, all observations examined in the regressions for subcomponents are also contained in the main regression for innovation performance, ensuring a degree of comparability. Tables for specific descriptive statistics can be provided by the authors.

[2] Detailed regression results with market novelties as the dependent variable can be provided by the authors upon request. The main results appear robust against other potentially relevant controls, are largely supported by regressions excluding lags and are not driven by differences in R&D intensity. Without the inclusion of lags, the APD coefficients for all groups are slightly lower (which is unsurprising given the time which may be required for the effects of cooperation to feed through). However, between-group differences have the same direction and are similar in magnitude (about a factor 3 for the APD linear coefficient). Therefore, the observed between-group differences in effects do not seem to stem from differing 'feed through time'. Moreover, also without lags, an inverted U-shape is only found for development-oriented firms and the differences in effects of APD on market novelties again appear strongest.

[3] Result table can be provided upon request.

magnitude for research-oriented firms and is significantly larger than for development-oriented firms (p = 0.0031).

Table 7 Tobit regression estimates: Partner combinations and innovation performance

Dependent variable: sales share of new and sig. improved products	(1) Partner combinations by category			(2) Partner combinations by domestic / abroad		
	Full	Research	Develop.	Full	Research	Develop.
Hor only	5.967	7.410	5.954			
	(4.762)	(10.59)	(5.206)			
Vert only	3.597*	3.950	3.736*			
	(1.839)	(5.030)	(1.957)			
Scie only	-4.441	-14.81**	-0.899			
	(3.603)	(6.651)	(4.128)			
Vert & Hor	5.843**	9.521	5.020*			
	(2.629)	(6.350)	(2.863)			
Scie & Hor	8.885	-3.756	10.70			
	(6.059)	(15.07)	(6.702)			
Vert & Scie	3.208**	0.099	3.402**			
	(1.496)	(3.596)	(1.629)			
Vert & Hor & Scie	6.557***	19.90***	4.217*			
	(2.053)	(4.547)	(2.266)			
Domestic only				3.293*	-1.113	4.098**
				(1.770)	(4.252)	(1.935)
Abroad only				4.333*	-5.353	5.809**
				(2.555)	(6.677)	(2.739)
Domestic & abroad				4.362***	8.114***	3.569***
				(1.233)	(3.068)	(1.337)
Controls included						
Tot. no. observations	3,757	637	3,120	3,757	637	3,120
(uncensored)	(3,116)	(513)	(2,603)	(3,116)	(513)	(2,603)
Wald $\chi 2$	619.67***	177.53***	527.64***	610.38***	152.59***	535.09***
Prob > $\chi 2$	0.000	0.000	0.000	0.000	0.000	0.000
Log Likelihood	-15,444	-2,533	-12,867	-15,448	-2,543	-12,868

Notes: Standard errors in parentheses (clustered at the firm level).

For these development-oriented firms, on the other hand, vertical cooperation shows clear positive effects. Regardless of whether it is used alone (Vert. only), combined with horizontal partners (Vert. & Hor.), combined with science partners (Vert & Scie.) or combined with horizontal and science partners (Vert. & Hor. & Scie): vertical cooperation always appears to exhibit a significant positive effect on the innovation performance of development-oriented firms (unlike cooperation which excludes vertical partners). Another noteworthy result is the negative coefficient for 'Science only' in research-oriented firms, with important implications to be discussed below.

Turning to the results on geographical diversity, no significant differences are detected between research- and development-oriented firms for a combination between domestic cooperation and cooperation abroad. Still, diversity again appears clearly as the most innovation-enhancing strategy for research-oriented firms.

Discussion

In sum, the results can be taken as evidence that in their attempts to innovate, development-oriented firms (ceteris paribus) benefit from selectivity in favor of vertical partners, whereas research-oriented benefit most from diverse alliance portfolios. Specifically, the overall effects of APD on innovation performance were found to be stronger for research-oriented firms than for development-oriented firms (H1) and only for the latter, the typical inverted U-shaped pattern was estimated (H2).[1,2] Moreover, the research-specific diversity effects were found to be strongest for market novelties (H3) and they were found to exist both in terms of partner categories and geography (H4).

Presumably, these differences in 'diversity effects' are attributable to the higher marginal benefits which research-oriented firms enjoy when increasing the number of partners. These firms tend to face a number of high obstacles in their innovation processes (often domestically and abroad), which only a *variety* of different partners can effectively help overcome in combination. Hence, if research-oriented firms use collaboration as a 'coping mechanism', combining different partners is key for their innovative success. Because such diversity helps research-oriented firms overcome crucial innovation obstacles, the resulting benefits can be very high and even offset high diversity costs.

For development-oriented firms, however, the costs of diversity should have a stronger impact. Here, the (supposedly similar) marginal costs of additional partners are larger relative to the (lower) marginal benefits. This gives the marginal costs a higher relative weight and makes them catch up with marginal benefits sooner.

Thus, it is presumably the absence of high marginal benefits (leading to higher *net* costs), which eventually causes the 'APD-innovation performance relationship' to tip at approximately nine partners for development-oriented firms.[3]

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[1] Notably, an invered U-shaped pattern for development-oriented firms was estimated for all subcomponents of innovative sales (additional result tables are available upon request by the authors).

[2] Perhaps, the much higher prevalence of these firms (highly research-intensive firms are quite rare) goes some way in explaining the inverted U-shaped patterns, which have generally been found in other studies.

[3] Naturally, the reality of rising costs also exists for research-oriented firms: also for these firms, the marginal costs are eventually expected to catch up with the marginal benefits as the number of partnerships is extended indefinitely. However, the present analysis does not capture such an 'indefinite' number of partnerships, but only a limited degree of diversity.

Apart from these different diversity effects, another important finding to discuss are the persistent negative effects of 'Science only' cooperation for research-oriented firms: as shown in the descriptive results, research-oriented firms use this strategy particularly frequently (see Table 5). Although partnerships with science organizations seem to be valuable for these firms, they appear to be conducive to innovativeness only when they are combined with other forms (in the sense of a necessary, but insufficient condition).

This may be due to various reasons. For instance, from the perspective of a sequential adoption of partnerships (Beck & Lopes-Bento, 2015), this partner category may often constitute an unsuitable starting point due to its idiosyncratic nature.[1] In addition, while this partner category seems highly beneficial in the ideation phase and in defining new trajectories, it may be less effective in helping a firm transform research findings into marketable products and to commercialize them. Together, these factors call for a combination of science partnerships with other partnership forms, especially for research-oriented firms.

Conclusions

In their note on the newly established Swiss Innovation Park in Zurich, Sauter Sauter et al. (2014, p.61) refer explicitly to 'research-intensive firms' in advocating the benefits of interacting with diverse partners:

> "To increase innovation, research-intensive firms need to both possess internal knowledge and obtain external knowledge from partners, universities, competitors, customers and suppliers."

This indicates that scientists are already (implicitly) aware of the supposed benefits which particularly research-oriented firms derive from working with diverse partners. This study has presented some first direct evidence for this, by examining the output effects of diverse R&D cooperation with a systematic distinction between research- and development-oriented firms.

Indeed, research-oriented firms seem to constitute a (small) subgroup of R&D active firms with special attributes. These firms aim at creating novel research-intensive products, often with a specific goal to reach new markets, but the hurdles they need to overcome on this path are particularly high. Compared to the rest of R&D active firms, these firms operate in a much more obscure environment, characterized especially by (a) lack of information on the state of technology (b) severe financing and regulatory constraints as well as (c) a specific need to transform scientific results into specific marketable products.

In such an environment, drawing from a diverse set of cooperation partners seems highly beneficial. The obstacles faced by research-oriented firms are often so diverse that no single partner type can be effective in helping to overcome all of them. However, different partner types can make a valuable contribution to this end. In other words, if R&D collaboration is used by research-oriented firms as a strategy to overcome innovation obstacles, combining diverse partners appears as the most promising strategy.

[1] This idea may be supported by Leiponen and Helfat (2010), who suggest that the absorption of scientific knowledge coming from universities is likely to require the largest relative amount of absorptive capacity.

Things look differently for development-oriented firms. While these firms are expected to face similar marginal costs of additional partners according to the logic of transaction cost economics, the benefits they derive from combining different partner types are presumably much lower. Together, this leads to higher *net costs* of diverse cooperation strategies for development-oriented firms. Our results are largely in line with these ideas. In fact, only for development-oriented firms, an inverted U-shaped effect of alliance portfolio diversity on innovation performance is detected over the observed range of partners. Consequently, the *overall* effects of partner diversity on innovation performance are also found to be less positive than for research-oriented firms.

The idea that partner diversity helps research-oriented firms overcome high hurdles has further implications for the *type* of innovation it predominantly supports in these firms. Indeed, regressions on subcomponents of innovative sales indicate that the distinct effects are strongest on market novelties.

Further results on the effects of partner combinations largely confirm the 'research-specific diversity benefits' in either of the observed dimensions. Both combining diverse partner categories as well as combining domestic with international cooperation appears to be highly conducive to the innovation performance of research-oriented firms.

Most importantly for research-oriented firms (given their frequent use of 'Science only' cooperation), there is ample evidence that for these firms, relying on a science partner is usually not enough. Development-oriented firms, on the other hand, seem to benefit from selectivity in terms of their most common partner: these firms' innovation performance is significantly enhanced by cooperation agreements with vertical partners, even when these are used in isolation. This is in line with the more continuous innovation activity of these firms, supposedly relying heavily on sustained feedback loops along the value chain.

Together, the evidence highlights the importance of alliance portfolio *diversity for research*-oriented firms and of portfolio *selectivity for development*-oriented firms. In light of these results, the firm's own research or development-orientation may constitute an additional important point of reference for managers to assess the firm-specific benefits of a diverse collaboration strategy. Whereas strongly development-oriented firms need to be especially aware of the downsides of an excessively broad cooperation strategy and thus focus on specific partnerships which support their continuous development activities, strongly research-oriented firms may want to make more extensive use of such diversity.

The research presented here was still limited in a variety of ways. First, although the results of the 5-point Likert scale on expenditures turned out to be highly consistent with theory and intuition, it did not allow for an expression of orientation in terms of a truly continuous measure. Secondly, the analysis did not systematically consider the various complementarities which can exist between 'R' and 'D' when these are extensively used together. Finally, the role of research-orientation needs to be examined much more thoroughly. Particularly the exploration of more 'continuous' research- and development-orientation seems to be a worthwhile goal.

In spite of the limitations of this analysis and all the questions that remain unanswered, the importance of separating 'R' and 'D' in this context seems clear. Such a distinction, in combination with the results of previous studies, should lead to important new insights aiming to the main goal – an adequate understanding of the firm-specific benefits of collaboration diversity.

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